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Simulation Assessment of Synthetic Vision Concepts for UAV Operations

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14. ABSTRACT
The Air Force Research Laboratory's Human Effectiveness Directorate supports research addressing human factors associated with Unmanned Aerial Vehicle (UAV) operator control stations. One research thrust focuses on determining the value of combining synthetic vision data with live camera video presented on a UAV control station display. Information is constructed from databases (e.g., terrain, etc.), as well as numerous information updates via networked communication with other sources. This information is overlaid conformal, in real time, onto the dynamic camera video image display presented to operators. Synthetic vision overlay technology is expected to improve operator situation awareness by highlighting elements of interest within the video image. Secondly, it can assist the operator in maintaining situation awareness of an environment if the video datalink is temporarily degraded. Synthetic vision overlays can also serve to facilitate intuitive communications of spatial information between geographically separated users. This paper discusses resu7lts from a high-fidelity UAV simulation evaluation of synthetic symbology overlaid on a (simulated) live camera display.

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Simulation assessment of synthetic vision concepts for UAV operations

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ABSTRACT

The Air Force Research Laboratory's Human Effectiveness Directorate supports research addressing human factors associated with Unmanned Aerial Vehicle (UAV) operator control stations. One research thrust focuses on determining the value of combining synthetic vision data with live camera video presented on a UAV control station display. Information is constructed from databases (e.g., terrain, etc.), as well as numerous information updates via networked communication with other sources. This information is overlaid conformal, in real time, onto the dynamic camera video image display presented to operators. Synthetic vision overlay technology is expected to improve operator situation awareness by highlighting elements of interest within the video image. Secondly, it can assist the operator in maintaining situation awareness of an environment if the video datalink is temporarily degraded. Synthetic vision overlays can also serve to facilitate intuitive communications of spatial information between geographically separated users. This paper discusses results from a high-fidelity UAV simulation evaluation of synthetic symbology overlaid on a (simulated) live camera display. Specifically, the effects of different telemetry data update rates for synthetic visual data were examined for a representative sensor operator task. Participants controlled the zoom and orientation of the camera to find and designate targets. The results from both performance and subjective data demonstrated the potential benefit of an overlay of synthetic symbology for improving situation awareness, reducing workload, and decreasing time required to designate points of interest. Implications of symbology update rate are discussed, as well as other human factors issues.

Keywords: synthetic vision, conformal overlay, situation awareness, unmanned aerial vehicle, UAV, update rate

1. BACKGROUND

The success of unmanned aerial vehicles (UAVs) in recent military situations has led to increased interest in their capabilities and their application to a variety of missions. Because there is no onboard crew, UAVs offer a number of distinct advantages to traditional, manned aircraft, especially for dull, dirty, and dangerous missions.[1] However, the physical separation of the crew from the aircraft also presents additional challenges to the effective design of the UAV control station. Numerous human factors issues such as system time delays, poor crew coordination, high workload, and reduced situational awareness may negatively affect mission performance.[2] When onboard an aircraft, a pilot and crew receive a rich supply of multi-sensory information instantaneously regarding their surrounding environment. UAV operators, however, may be limited to a time-delayed, reduced stream of sensory feedback delivered almost exclusively through the visual channel. Making the information-management demands on the UAV operator even worse are the massive amounts of data now available with net-centric warfare doctrine. Plus, as UAV platforms become more autonomous, it is envisioned that a single crew, or one operator, will be tasked with multiple UAVs simultaneously, in contrast to the current manning of one or more operators to control a single UAV.[3]

The sheer volume of critical disparate data and imagery pertaining to multiple UAVs, together with the new paradigm of network-centric warfare, will place a heavy burden on UAV operators who must rapidly make time-critical decisions and inputs to ensure successful mission completion. Besides monitoring the maneuvering of multiple UAVs

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and the operation of their respective subsystems, operators will need to decipher sensory information and make assessments and decisions concerning potential threats. With the complexity of UAV systems and mission dynamics, it is also likely that the operator will have to intervene with the subsystems of one or more UAVs to handle contingency operations. In order for UAV operators to rapidly understand incoming data and act on assets under their control, more sophisticated enabling visualization tools are needed to promote real-time interpretation of data and increase situation awareness.

Synthetic vision systems[4] (also termed augmented reality) can potentially enhance data interpretation and the level of operator situation awareness, and consequently influence the decision making capability and the ability to make timely responses to contingencies. With this technology, spatially-relevant information, constructed from databases (e.g., terrain elevation, maps, photo-imagery, etc.) as well as networked information sources, can be represented as computer symbology and overlaid conformal, in real time, onto operator displays. This computer-generated symbology appears to "co-exist" with real objects in the visual scene, highlighting points of interest to operators.

2. SYNTHETIC VISION CONCEPTS FOR UAV OPERATIONS

2.1 Potential Applications for UAVs

It is anticipated that a synthetic visual overlay technology could benefit UAV missions. Perhaps one of the most promising UAV application for synthetic symbology is to augment the display showing video imagery from various cameras mounted on the UAV. Pilots use imagery from the UAV's nose and gimbal cameras to verify clear path for taxi/runway operations, scan for other air traffic in the area, and identify navigational landmarks and potential obstructions. Sensor operators use imagery from a gimbal-mounted camera to conduct a wide variety of intelligence, surveillance and reconnaissance activities as well as to directly support combat operations. However, video imagery quality can be compromised by narrow camera field-of-view, datalink degradations, poor environmental conditions (e.g., dawn/dusk/night, adverse weather, variable clouds), bandwidth limitations, or a highly cluttered visual scene (e.g., in urban areas or mountainous terrain).

A synthetic vision system can potentially enhance UAV operator interpretation of data/imagery, improve situation awareness, and ameliorate negative video characteristics.[5] It could improve operator situation awareness by highlighting elements of interest within the video image such as threat locations, key landmarks, emergency airfields, etc. Secondly, it can assist the operator in maintaining situation awareness of an environment if the video datalink is temporarily degraded. Synthetic vision overlays could also serve to facilitate intuitive communications of spatial information between geographically separated users. The application of a synthetic overlay to the video imagery display in UAV stations is illustrated in Figures 1 and 2. Figure 1 shows synthetic vision symbology developed by Rapid Imaging Software, Inc. (SmartCam3D) added to (simulated) UAV video imagery. Figure 2 shows another synthetic overlay concept, termed "picture-in-picture" whereby synthetic-generated imagery surrounds the real video imagery on the display. This concept affords virtual expansion of the available sensor field-of-view well beyond the physical limits of the camera, potentially improving large area situation awareness.

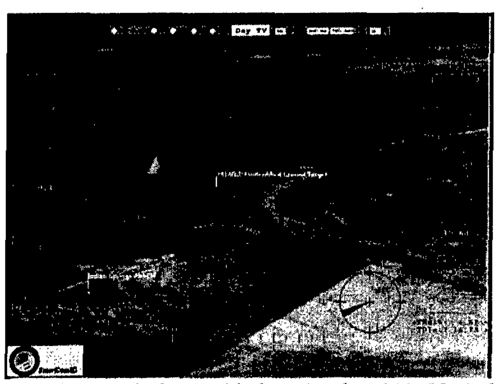

Figure 1: Synthetic vision symbology added to simulated UAV gimbal video imagery (symbology marking threat, landmarks, areas of interest, and runway).

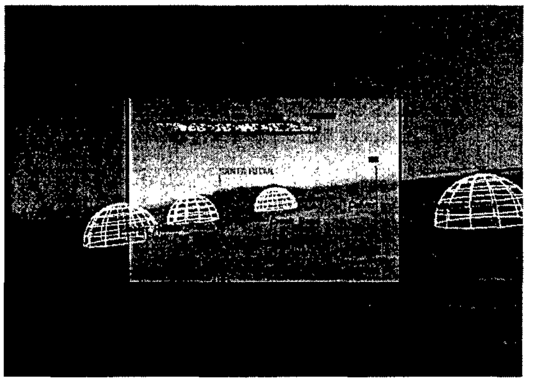

Figure 2: Picture-in-picture concept, with real video imagery surrounded by synthetic-generated terrain imagery.

2.2 Past research addressing application of synthetic vision systems to UAVs

Presentation of a synthetic visual overlay in a conformal manner with sensor imagery has been demonstrated in the laboratory to reduce scanning time, reduce the need to mentally integrate spatial information from disparate sources, and facilitate attentional management.[6] To date, application research has primarily focused on how synthetic overlays can aid piloting tasks during manned flights. In fact, there is a large body of research showing the utility of synthetic vision systems for both military and civilian manned flight applications. For instance, flight guidance overlay symbology has been found to be valuable for reduced visibility conditions, especially during landings.[7]

Synthetic overlay research for UAV applications is scant in comparison to research for manned applications. The majority of efforts to date have involved developing concept demonstrations and acquiring subjective data from subject-matter-experts. For instance, in an U.S. Army Research Laboratory effort, synthetic vision overlay concepts are being employed in the development of displays to support multi-UAV control.[8] On the format, lines radiate from the UAV symbols to show their visual field-of-regard in relation to themselves and the ground. Multicolored lines on the ground delineate political boundaries. Ground targets of interest are highlighted with black hexahedrons and a north facing arrow fixed on the screen provides geographic orientation and a situation awareness enhancement. Tests are ongoing, but results to date suggest that the ability to combine real time video imagery with virtual databases will enhance situation awareness and improve crew coordination. Academic research in the Netherlands has also addressed the feasibility of using synthetic vision technology for UAV operator support. Using existing synthetic vision software components, a UAV mission management system was created to support ongoing research to see if computer generated imagery can increase situation awareness, both for the current situation as well as understanding the effect of changes on future situations in the mission.[9, 10]

In a recent study conducted by the U.S. Air Force Research Laboratory, both performance and subjective data were obtained during the evaluation of three synthetic visual overlay concepts for improving the situation awareness of UAV sensor operators.[11] Results indicated that the concepts showed promise for improving UAV operations, particularly the use of virtual flags to highlight landmarks. The overlay of virtual flags significantly reduced landmark designation times (by 40-58%) and served to mitigate the negative effect of low camera slew accuracy. These data also did not show any cognitive tunneling effects. Attention/cognitive tunneling occurs when the operator becomes fixated on the synthetic cue itself (or objects to which attention is directed by the synthetic cue) to such an extent that other, un-cued events known to be of importance are not attended to.[12] In the case of UAVs, this may result in the failure to detect unexpected, high priority objects .

Although the data from this recent study did not show any cognitive tunneling effects, it may be that the highly salient unexpected target utilized washed out any tunneling effects. Follow-on research is needed to further examine the potential for cognitive tunneling, in addition to a myriad of other human factors issues in regards to synthetic vision systems (see 2.3).

2.3 Human factors issues with UAV synthetic vision systems

There are numerous human factors issues to consider in the application of synthetic vision systems to UAVs.[13] For instance, there are multiple issues on how the synthetic vision symbology should be presented in terms of optimizing each symbology element and determining if the symbology should appear on a separate display versus an overlay and, if the latter, if it should be superimposed versus "scene-linked." Applications also need to take into account the potentially negative effects of information clutter by only including elements that will benefit the operators' situation awareness and performance, and employing design features that minimize clutter effects. Information view management technologies can be used to optimize the visibility of the synthetic vision symbology for a variety of viewing situations, as well as indicate the criticality, urgency, reliability, and timeliness of information depicted by elements. Blending techniques may be appropriate, whereby the transparency of the synthetic symbology is manipulated. The performance of the synthetic vision system (registration errors and time delays) can also impact the utility of the symbology. Besides displays issues, there are also control issues: what control interfaces will be used by operators to modify the symbology and how distributed network collaborative communication of synthetic information will be implemented. In sum, evaluations (usability, simulation, and flight test) are needed to optimize how synthetic information is implemented in UAV applications and to confirm that the synthetic vision system will benefit UAV operations and result in increased mission effectiveness. This paper reports the results of a recent simulation assessment of update rate on synthetic symbology utility for a UAV operator task.

3. METHOD

3.1 Objective

The rate at which data on the (simulated) UAV's position in space is fed to the software that generates the synthetic symbology was manipulated to determine its effect, if any, on the utility of the synthetic symbology presented for task completion. Update rate is a factor of interest because it, in turn, contributes to the appearance/behavior of the synthetic symbology, as well as registration errors. At higher rates, the synthetic symbology appears smooth, not jumpy, and with no delay. At slower rates, the symbology stutters or jumps and it may be possible to detect delays. Even if the symbology appears to jump, etc., it is possible that this is not distracting to operators and/or may not impact task performance. Another possibility is that the effect of update rate may differ as a function of task type. For tasks where the synthetic symbology is used to highlight objects in the real world, it is especially important for the synthetic and real worlds to be properly aligned (i.e., registered) with respect to each other on the display, or the illusion that the two worlds coexist will be compromised.[14] Slower update rates may contribute to the registration error, making it more difficult to discern what real world element is being highlighted by a synthetic cue. In contrast, for tasks in which the operator needs to retrieve information from the synthetic symbology (for example, enter text displayed on a synthetic flag), the stability of the symbology may be more important than how recently it was refreshed. In this case, update rates very low and very high may be better than update rates in a middle range that result in the symbology jumping around.

For the present experiment, seven different telemetry update rates were examined: .5, 1, 2, 4, 6, 10, and 24 Hz. These update rates were chosen to obtain task performance data with several candidate operational rates for a variety of UAVs. Another objective was to explore if there is a point where task performance starts to degrade in the relationship between telemetry update rate and the delay in the presentation of synthetic information. This relationship can be described as a sharp curve with a 2 second delay at the .5 telemetry update rate, dropping to a 0. 25 second delay by 4 Hz.

3.2 Simulation environment

The UAV sensor operator workstation (Figure 3) had head-level and upper 17" color displays, as well as two 10" head-down color displays (HDDs). During the experiment, participants focused on the head-level display presenting simulated video imagery from the UAV's gimbaled camera, along with head-up display (HUD) sensor symbology. The simulated imagery was a realistic database model of southern Nevada. For the present experiment, the upper display was covered, such that participants could not see its map with symbology identifying current UAV location, flight corridor, and landmark locations. This was done to control the source of information for all participants – participants could only use the target deck flip book and the head-level camera display to complete tasks. Information on the two HDDs presenting subsystem information was also not needed for completion of the tasks. However, this information was not covered, to add visual complexity to the workstation. Participants used the center keyboard for data entry. To change

the camera's field of view, participants manipulated the right and left joysticks to control the camera's orientation and zoom factor, respectively. The simulation was hosted on six Pentium PCs.

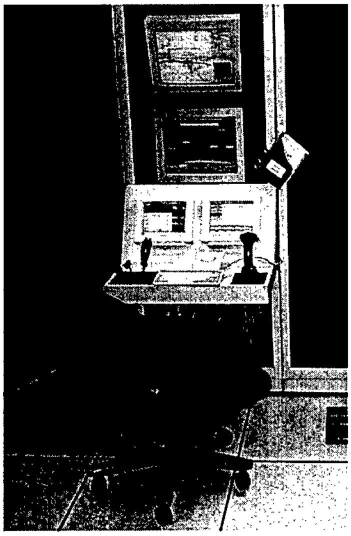

Figure 3: UAV sensor operator workstation simulator.

3.3 Experimental procedures:

Participants were given an overview of the experiment. They were told that the goals of the experiment were to: 1) gather opinions on whether the synthetic symbology presented helped completion of the tasks, and 2) evaluate the appearance/behavior of the synthetic symbology, as determined by "characteristics" the experimenter manipulated in the generation of the symbology. Participants were <u>not</u> briefed that the update rate would be varied and all trial instructions were identical, regardless of what update rate was in effect. Participants practiced each task separately until performance stabilized. Each participant spent 4-6 hours completing the training and experimental trials.

3.4 Experimental tasks

There was no flight control task; the UAV automatically loitered in a racetrack pattern. Participants completed four types of sensor operator (SO) tasks, described below. Only the Target Marking task and data will be addressed in the present paper.

1. <u>Target marking</u>: center cross hairs and designate (press joystick button) as many unmarked tanks as possible in 90 seconds. If an unexpected, high-priority target (fuel truck) is spotted, designate it as well.

2. <u>Large area search</u>: center cross hairs over landmark instructed to find and press joystick button. Performance was examined both with "PIP-On" and "PIP-Off" conditions.

3. <u>Route tracking</u>: center cross hairs on instructed route and move crosshairs along route highlighted by symbology.

4. <u>Data entry</u>: after designating landmark, using keyboard, enter numeric information displayed on flag that appears.

The number of trials completed with each of the 4 SO tasks is shown in Table 1. A total of 42 experimental trials were conducted with each participant.

TABLE 1. Number of Trials with Each SO Task Type

Type	# of Trials	SO Task Type	
1	7	Target Marking/No Unexpected Target Present	
	7	Target Marking/Unexpected Target Present	
2	7	Large Area Search:	PIP-On
	7	Large Area Search:	PIP-Off
3	7	Route Tracking	
4	7	Data Entry	

3.5 Experimental design

A within-subjects design was utilized. All fourteen male participants (average age=24.7 years) completed trials with each of seven Telemetry Data Rates. Performance on four types of SO tasks were evaluated with each update rate (target marking, large area search, route tracking, and data entry; Table 1). For the large area search task, performance was examined both with PIP-On and PIP-Off. The 42 trials were blocked by SO task type: one of the four task types was examined before each of the other SO task types. The order of the four SO task types was counterbalanced such that each of the four task types followed each of the other types an equal number of times, for twelve of the participants. The order was randomized for the remaining two participants.

The procedure to determine the order of trials within each type of SO task differed across task types. For the SO task to be reported in the present paper, Target Marking Task, a total of 14 trials were conducted per participant. Two trials were conducted (one with an unexpected target and one without an unexpected target) with each of the 7 update rates. The order of the 14 trials was randomized independently for each of the 14 participants, with several constraints: a) the two trials with each update rate were separated by at least two trials with different update rates and b) either type of target marking trial (unexpected or no unexpected target) could not occur more than 3 times in a row. This procedure helped minimize the possibility that participants developed expectancy as to which trials had an unexpected target. With this procedure, the order in which the update rates were experienced was randomized. An adaptation period preceded each trial to familiarize participants with the appearance/behavior of the symbology (determined by the update rate in effect).

A total of 7 target sets were used. The assignment of target set number to update rate was randomized independently for each participant with two constraints: a) a given target set was used twice with each update rate (once with and once without an unexpected target) per participant, and b) each target set was used an equal number of times (twice) with each update rate across participants.

3.6 Target Marking Task

The participants' task was to manually control the camera orientation to locate and designate as many tanks as possible in a 90 second period. For each trial, participants hit a red key on the keyboard to auto slew the camera to an "Adaptation Area". Once the slew stopped, the participants pressed the "M" key to gain manual control of the camera. The participants were trained to then move the camera around in the Adaptation Area to become familiar with the appearance/behavior of the synthetic symbology under the "characteristics" (i.e., update rate) in effect for that particular trial. After 10 seconds, the camera auto slewed to the starting point for that trial. This point was in the same field-of-view as a "Target Marking Area" that was enclosed by a green synthetic boundary line (area size approximately 0.1 square mile).

The imagery in the Target Marking Area (Figure 4) contained 30 tanks that were pre-marked with green flags labeled "Tank" and 15 "target" tanks that had no flags. (Participants were not briefed on the number of non-target or target tanks per trial.) The target tanks were randomly dispersed in the area according to three difficulty levels, based on the assumption that target tanks that were not close to pre-marked tanks would be easier to find. At full-zoom screen size,

"hard" target tanks were located 2 cm (as measured on the front of the monitor) from two pre-marked tanks. "Medium" and "easy" tank levels were 4 and 6 cm, respectively. The placement and difficulty was randomized and kept balanced such that there were an equal number of hard, medium, and easy target tanks in each trial. For trials in which an unexpected, high-priority target was also present, an image of a fuel truck was located such that two constraints were met: the truck was within 5 degrees field-of-view from the visual center point required for designation of one of the 15 target tanks, and b) the truck was either on or just outside the synthetic boundary line denoting the Target Marking Area.

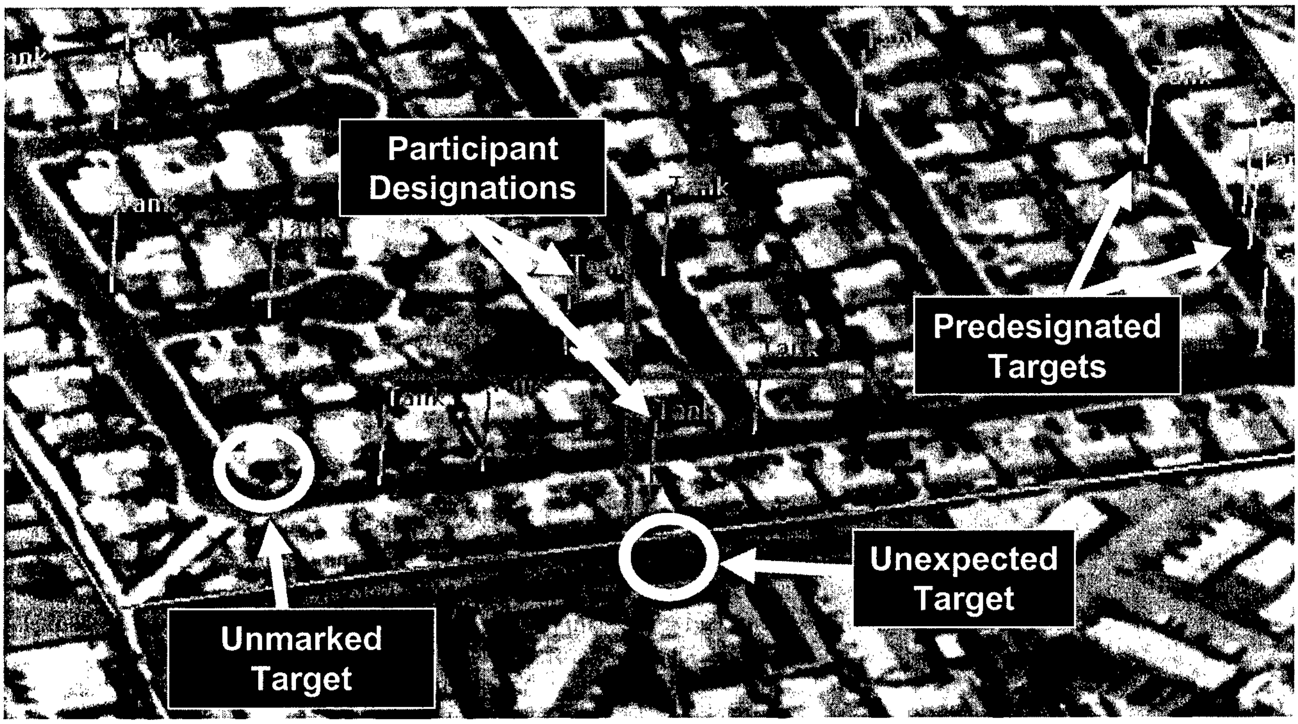

Figure 4: Sample Target Marking Area showing simulated imagery, tanks, and fuel truck (unexpected target), as well as synthetic overlay (boundary line and flags).

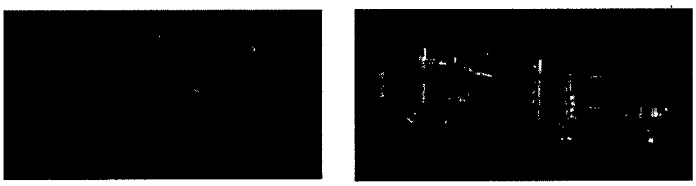

Figure 5: Illustration of tank (left) and unexpected high priority fuel truck (right) at one orientation.

When slewing stopped in the same field-of-view as the Target Marking Area, the participants again pressed the "M" key to resume manual camera control and adjusted the left joystick to zoom in all the way to locate/designate tanks. Participants then moved the right joystick to control camera orientation in order to center the cross hairs on each target tank and press the designate button on the joystick. Once a target tank was designated, a green flag was presented at the location stating "Tank". If the unexpected, high-priority truck was located, participants were trained to designate it as rapidly as possible and then resume the task of locating/designating the other tanks until the time limit expired. Participants also heard an auditory "ding" whenever a flag appeared as a result of hitting the designation button when the cursor was centered on a tank or truck. If the designation button was pressed when the cursor was not centered on a target, then a flag was dropped, but an auditory cue was not presented. Participants had 90 seconds to locate and

designate 15 target tanks (and 1 truck, if present), with the goal of only designating each one once. When the time limit expired, the simulation froze and a message "Trial Over" was displayed.

After each trial was completed, participants completed a post-trial questionnaire that involved rating the appearance/behavior of the synthetic symbology for that trial, as well as the degree to which it was distracting and impacted task performance. There were also scales for participants to rate their perceived situation awareness, task difficulty, task performance and workload for that trial. After completion of all 14 target marking trials, another questionnaire was administered which asked whether the participants' strategy changed depending on the appearance/behavior of the symbology and whether they had suggestions on how the synthetic symbology could be improved.

3.7 Measures

The number of 15 "target" tanks designated per trial were recorded, as well as the number of these marked more than once. The number of false alarms (when participants marked one or more of the pre-marked 30 tanks) was also tallied. Recorded "misses" were instances when the participant pushed the designation button and the cursor was not centered on a tank. Measures pertaining to the unexpected fuel truck target included whether or not it was designated.

Participants completed a questionnaire with seven rating scales after every trial. Four of the scales dealt with the participants' overall impression of that particular trial in terms of situation awareness, task difficulty, task performance, and workload. The three other rating scales on the post-trial questionnaire focused specifically on the synthetic symbology. After completion of all the trials, participants were given an opportunity to make comments on the strategy they used in the target marking task and on how the symbology might be improved.

4.0 RESULTS

Both the performance and subjective data were analyzed to determine if there were significant differences as a function of update rate. Mean measures were obtained and entered into an analysis of variance with the Huynh-Feldt epsilon correction applied. Post hoc analysis was done using Bonferroni pair-wise comparisons.

4.1 Performance data

Participants completed two types of 90-second target marking trials: target marking trials that had 15 unmarked tanks and no unexpected target, and target marking trials that had one unexpected target (truck) in addition to the 15 unmarked tanks. Table 2 summarizes the performance data results for these two types of trials.

These results showed that the target marking data generally did not significantly differ as a function of update rate for both types of target marking trials. To obtain a larger pool of data, it was decided to combine the data from the two target marking trials, even though half of these trials had one additional target for participants to find. With this pooled data, there was a significant effect of update rate on the number of targets marked ($F(6,78)=3.586$, $p=.004$; see Figure 6). Post-hoc Bonferroni paired t-tests showed a trend ($t(13)=3.587$, $p=0.070$); the average number of targets marked when the update rate was .5 Hz (7.429 targets) was less than the number marked with the 24 Hz in effect (9.000 targets). It should be noted, though, that the average number of targets marked across the seven update rates only varied by 1.75 targets, with the number of targets marked with .5 Hz less than the number of targets marked for all the other update rates.

This pooled data set underwent a separate analysis to examine if performance as a function of update rate differed depending on the target's difficulty level (easy, medium, or hard, determined by how close the target tanks were to other pre-marked tanks). However, the results still showed that there were no significant performance differences as a function of update rate (easy: $p=.949$, average=5.8; medium: $p=.958$, average=5.52, hard: $p=.586$, average=5.30).

TABLE 2. SUMMARY OF TARGET MARKING PERFORMANCE DATA

	Trials with No Unexpected Target	Trials with Unexpected Target
Number of Targets Marked (15 presented in each trial)		
Average; (Range); Std. Dev.	8.49; (7.29-9.07); 2.99.	8.82; (7.57-9.64); 3.14
Update Rate	$F(6,78)=1.838, p=.110$	$F(6,78)=2.026, p=.072$
Targets Marked More Than Once		
Average; (Range); Std. Dev.	Count = 5	Count = 1
Update Rate	Insufficient data for analysis	Insufficient data for analysis
Number of False Alarms*		
Average; (Range); Std. Dev.	0.30; (0.02-0.86); 0.56	0.25; (0.09-0.64); 0.51
Update Rate	$F(6,78)=2.763, p=.059$	$F(6,78)=1.733, p=.180$
Number of Misses**		
Average; (Range); Std. Dev.	5.60; (4.39-7.39); 3.97	5.67; (4.00-7.31); 4.68
Update Rate	$F(6,72)=2.285, p=.060$	$F(6,72)=2.002$, p=.125
Number of Unexpected Targets Marked (1 presented in each trial)*		
Average; (Range); Std. Dev.	Not Applicable	0.60; (0.43-0.91); 0.46
Update Rate		$F(6,78)=2.390, p=.036$; (post-hoc: 2 Hz < 4 Hz, $p=.095$)

* 3 outliers replaced with the grand mean.

** One participant's data removed from data set as average was 4.71 times other participants' combined average.

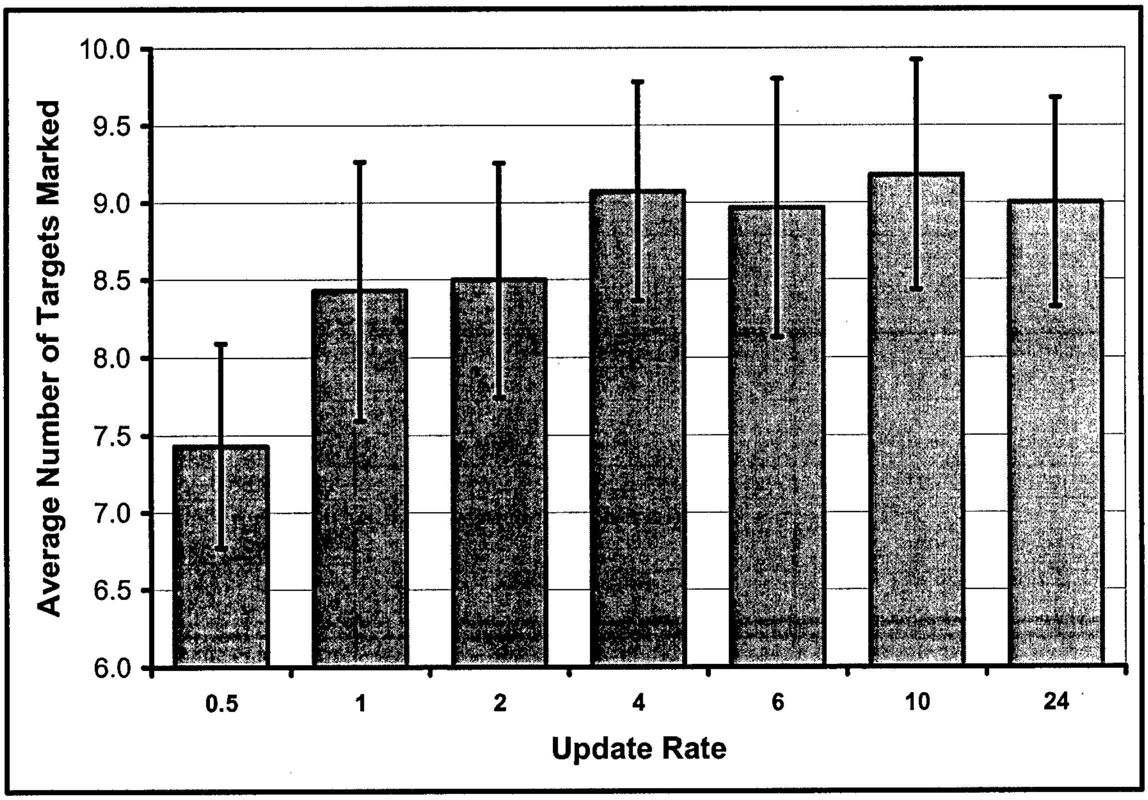

Figure 6: Average number of targets marked with each update rate for all target marking trials, both with and without unexpected target.

4.2 Subjective data

Four of the seven rating scales (all 7-point) dealt with the participants' overall impression of that particular trial in terms of situation awareness, task difficulty, task performance, and workload. For all factors, the ratings significantly differed as a function of update rate (see Table 3).

TABLE 3. SUMMARY OF SUBJECTIVE RATINGS ON TASK COMPLETION

Rating Factor	Update Rate	Post-hoc Bonferroni test
Situation Awareness (SA)	$F(6,78)=4.264, p<.05$	Less SA with 1 Hz than 10 Hz, $p<.05$
Task Difficulty (Figure 7)	$F(6,78)=9.050, p<.01$	.5 Hz harder than 24 Hz, $p<.01$ .5 Hz harder than 4,6,10 Hz, $p<.05$ 1 Hz harder than 24 Hz, $p<.05$
Task Performance	$F(6,78)=3.314, p<.01$	No significant differences
Workload	$F(6,78)=4.884, p<.01$	No significant differences

Generally, situation awareness ratings increased as the update rate increased. However, all average ratings were greater than zero on the rating scale, indicating that regardless of update rate, participants thought that they had situation awareness.

Average ratings for task difficulty (Figure 7) indicated participants perceived the target marking task harder with low update rates (.5 and 1 Hz) compared to the task with high update rates (4, 6, 10, and 24 Hz). The ratings for the two other factors showed similar trends: participants tended to rate their task performance higher and their workload lower for trials that had a higher update rate in effect.

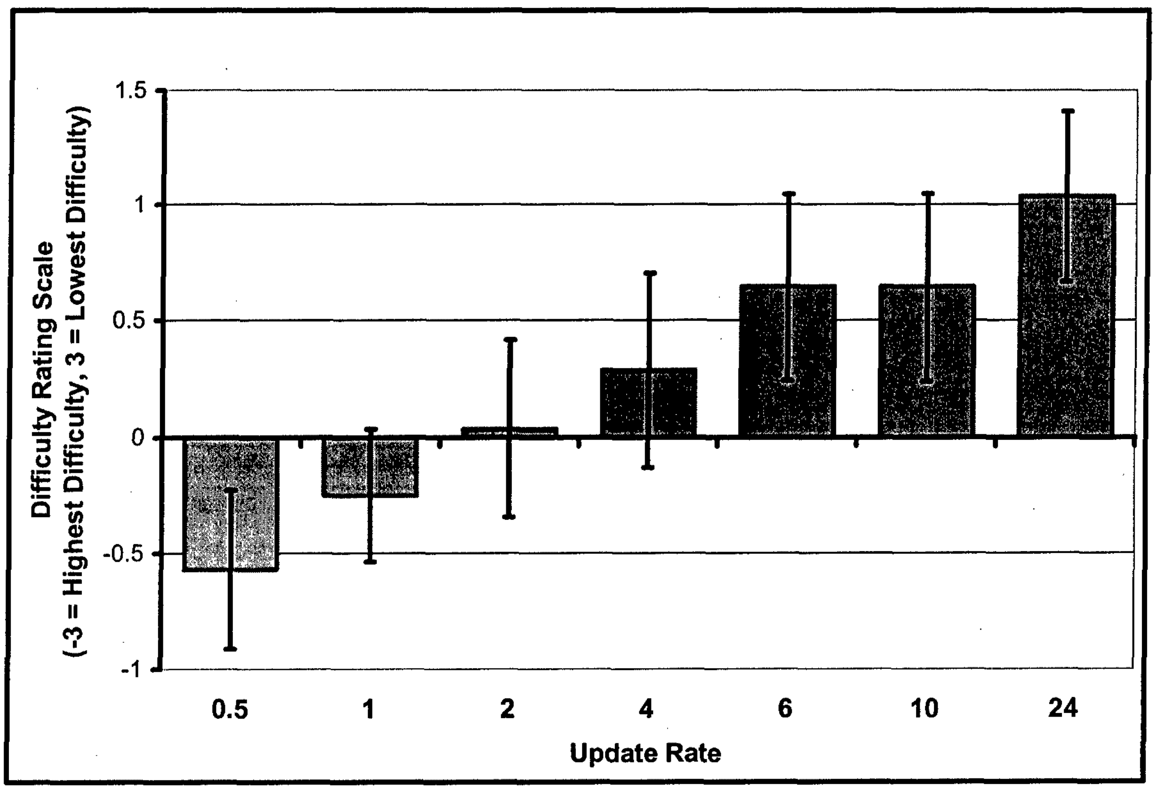

Figure 7: Participants' average rating on the perceived target marking task difficulty for each update rate.

The three other rating scales on the post-trial questionnaire focused specifically on the synthetic symbology. For all three scales, the ratings significantly differed as a function of update rate. These results are summarized in Table 4.

TABLE 4. SUMMARY OF SUBJECTIVE RATINGS ON SYNTHETIC SYMBOLOGY

Rating Factor	Update Rate	Post-hoc Bonferroni test
Appearance Figure 8	$F(6,78)=48.80, p<.001$	All comparisons, $p<.01$ Symbology with .5 Hz more degraded than all other rates 1 Hz worse than 4, 6, 10, 24 Hz 2 Hz worse than 6, 10, 24 Hz 4 Hz worse than 10 and 24 Hz
Distraction Figure 9	$F(6,78)=30.51, p<.001$	.5 Hz more distracting than 4,6,10,24 Hz ($p<.01$) 1 Hz worse than 4,6,10 Hz ($p<.01$) & 24 Hz ($p<.05$) 2 Hz worse than 6 & 10 Hz ($p<.01$) 4 Hz worse than 10 Hz ($p<.05$) 6 Hz worse than 10 Hz (($p<.01$)
Performance Impact Figure 10	$F(6,78)=19.48, p<.001$	All comparisons, $p<.01$ Performance impacted by .5 Hz more than 4, 6, 10, 24 Hz 1 Hz worse than 6, 10, 24 Hz 2 Hz worse than 10, 24 Hz

Figure 8 illustrates the data from the scale that asked participants to rate to what extent the appearance of the synthetic symbology was degraded (jumpy, delayed, not smooth, etc.). The data shown in Figure 9 is from the scale asking to what extent the appearance/behavior of the synthetic symbology was distracting to participants. For both of these questions, a 5-point scale was used. Participants were to choose a "not at all" category to indicate there was no degradation or distraction during that trial. For trials in which the symbology was degraded or distracting, the other four choices enabled participants to rate the severity of the problem. For both of these measures, the ratings significantly differed as a function of update rate. Generally, the slower the update rate, the worse the ratings, indicating that participants found the synthetic symbology degraded and distracting at the lower update rates.

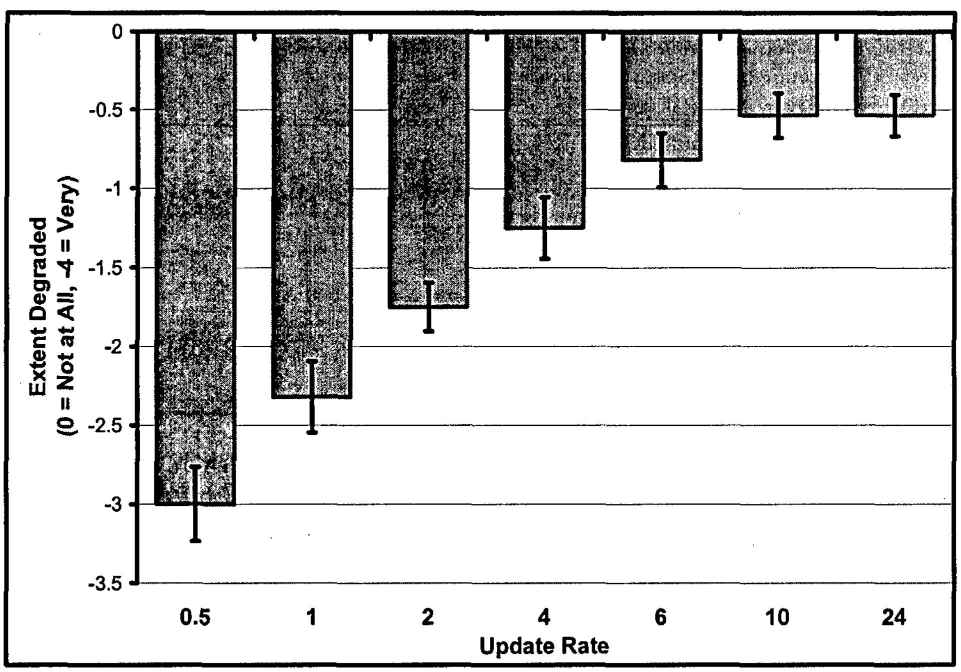

Figure 8: Participants' average rating on the appearance of the synthetic symbology, for each update rate.

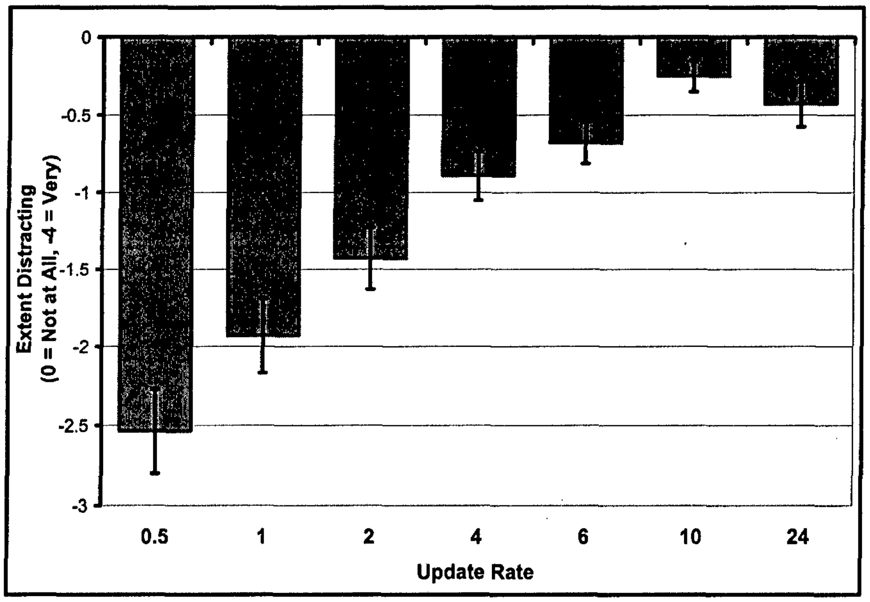

Figure 9: Participants' average rating, for each update rate, on whether the synthetic symbology was distracting.

The third rating scale addressing synthetic symbology asked to what extent the synthetic symbology impacted task performance. This question was included because even if the participants noticed degradation in symbology and/or found it distracting, it may not have affected task performance, in their view. There were seven rating options. Participants were to choose the middle category to indicate that they symbology had no impact on task performance for that trial. Otherwise they were to choose one of the three categories to the left or right to indicate the degree to which the synthetic symbology hurt performance or aided performance. Participant responses indicated that the .5 and 1 Hz update rates hurt task performance, whereas the other (higher) update rates aided performance, the higher the update rate, the more beneficial for task performance.

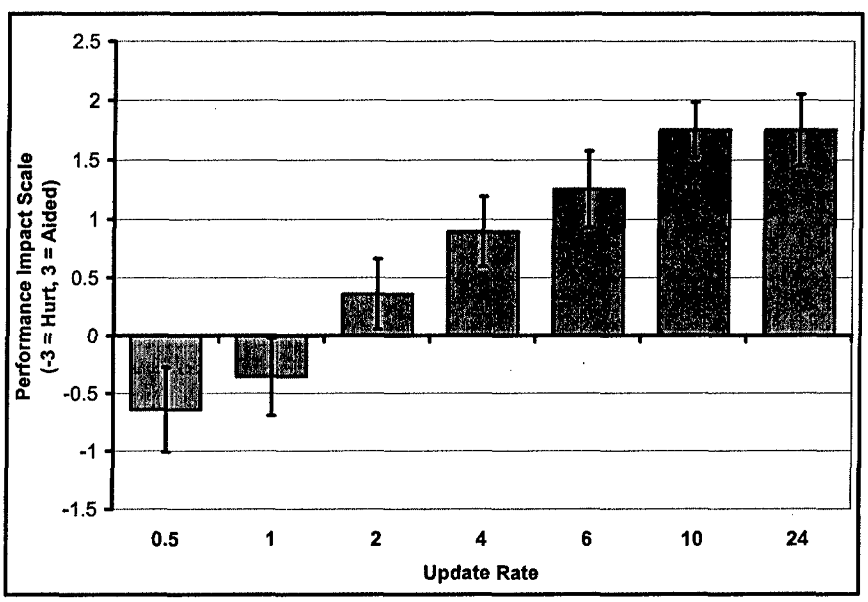

Figure 10: Participants' average rating on the impact of the synthetic symbology on task performance, for each update rate.

CONCLUSIONS

Participants performed well on the target marking task. On average they marked over half of the 15 unmarked tanks and usually caught the unexpected targets, despite the trials' short 90-second time limit. There were few instances of marking the same target twice, as well as misses and false alarms. Furthermore, this level of performance was fairly consistent across update rates. Although the performance data did not show a decrement as a function of update rate, the subjective ratings indicated that task performance was better, and the symbology less distracting, the higher the update rate. Generally, subjective ratings were particularly unfavorable for the .5 and1 Hz update rate conditions.

The fact that there were not consistent performance differences between update rates may reflect human adaptability, bringing resources to bear to ensure that the task is achieved regardless of the update rate. A few subjects mentioned that when the symbology was degraded (making the flag/tank correspondence less clear), they had to compare the pattern of the synthetic symbology with the pattern of tank images, to discern which had been marked. Another participant commented that when the symbology lagged or was choppy, more concentration was required. With only fourteen 90-second target marking trials, this extra effort (e.g., concentration) to maintain a high performance level did not have to be sustained for a long duration. It may be that differences across update rate would have been evident with more numerous trials, longer sessions, and/or realistic missions where a variety of tasks are being time-shared. It also may be that performance decrements would have occurred with less salient targets and/or a more cluttered scene.

Given that the participants' subjective ratings were consistent – symbology at high updates rates was less degrading and distracting and served as an aid to task performance, the conclusion can be made that the highest telemetry rate supported by the UAV system should be employed when applying a synthetic vision system. At a minimum, it is recommended that rates of 2 Hz or higher, be utilized. This conclusion, based solely on the present target marking data, should be revisited, once the results for the other three tasks examined in this study are available. It may be that another update rate will be identified as optimal when considering multiple types of SO tasks.

It is also important to note that there are several points in the overall system that can contribute to both time delay and registration error. For instance, the quality of the UAV positional data, is subject to quantization error, random delays, and basic measurement error, besides problems introduced by the telemetry system. If registration errors are systematic rather than variable, operators might be able to adapt. Indeed, that is one research question: How much registration error and time delay is tolerable for a UAV application before task performance degrades substantially? For some of these, it may be possible to provide a manual intervention whereby the operator can dynamically recalibrate the correspondence of the synthetic and real world. It also may be possible that advances in prediction algorithms may help overcome the limitations of imprecise and tardy data input to the synthetic vision system.

As was mentioned in the introduction, one concern with a synthetic vision overlay is the possibility that the operator's attention is tunneled such that key information is missed. The present experiment did not include trials without synthetic symbology to systematically test this issue. However, the results showing that 60% of the unexpected targets were marked suggest that the synthetic symbology utilized in the present experiment, for this task paradigm, did not result in cognitive tunneling.

In sum, the target marking task data from this experiment examining the effect of telemetry update rate on several representative sensor operator tasks provides further demonstration that a synthetic vision overlay aids performance, regardless of a range of update rates. There remain, however, numerous questions for the research community at large to address to ensure optimized integration of a synthetic vision system for UAV applications. It is highly recommended that resources be devoted to examining the application of synthetic vision systems to UAVs, as potential operational benefits include faster target prosecution, more targets serviced, and reduced potential for collateral damage.

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